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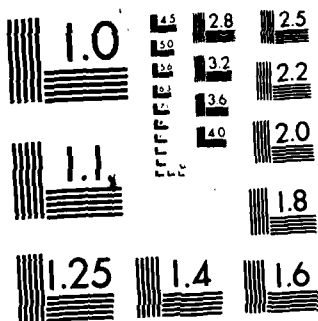
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ON THE EQUIDECOMPOSABILITY OF A REGULAR  
TRIANGLE AND A SQUARE OF EQUAL AREAS

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ABSTRACT

✓ This paper deals with the subject of the first chapter of the second author's book "Mathematical Time Exposures": The equidecomposability of a regular triangle and a square of equal areas. A new solution of the problem is given, which also shows that the solution of the problem as given in the third edition of Hogo Steinhaus, "Mathematical Snapshots", is not correct.

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# SIGNIFICANCE AND EXPLANATION

It is shown that the solution of the problem of the title, as given in the first snapshot of H. Steinhaus' "Mathematical Snapshots" is not correct. This is derived from a new solution of the problem.



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ON THE EQUIDECOMPOSABILITY OF A REGULAR TRIANGLE AND  
A SQUARE OF EQUAL AREAS

D. W. Crowe and I. J. Schoenberg

Two plane polygons are said to be equidecomposable if it is possible to decompose one of them into a finite number of parts which can be rearranged to form the second polygon (see [1] and [2, Chapter 1]). The proposition of our title is the subject of [2, Chapter 1, pp. 1-6], where Chapter 1 is entitled "On Steinhaus's first mathematical snapshot of 1939". The reason why we return to it now is to point out that the solution as sketched in Figure 2 on page 4 of [3] is not correct. This is shown by the following different solution of the problem.

Let  $T = ABC$  be a regular triangle having sided = 2 (Figure 1), where  $D, E, O$  are the midpoints of its sides. We choose the lines  $OB$  and  $OA$  as coordinate axes. Let  $0 < \xi < 1$  and  $F = (\xi, 0)$ ; on  $CB$  we take the segment  $GF$  of unit length, hence  $G = (\xi-1, 0)$ . Since  $DE = GF = 1$ , it follows that  $DEFG$  is a parallelogram. We join

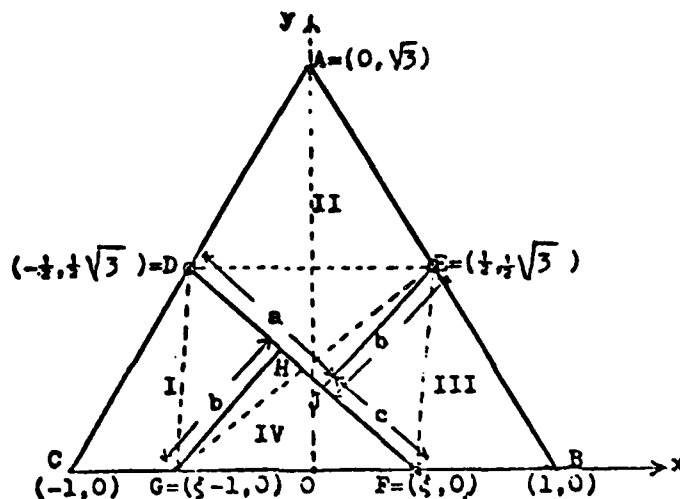


Fig.1

D to F, and draw GH and EJ perpendicular to DF. Finally, let T be dissected into three quadrilaterals and one triangle as follows:

(1) I:= CGHD, II:= ADJE, III:= PFJE, IV:= HGF.

Because DEFG is a parallelogram, we have the segments a, c, b, defined by

(2)  $a = DJ = HF$ ,  $c = DH = JF$ ,  $b = GH = JE$ ,

as indicated in Figure 1.

We claim: The triangle  $ABC = I \cup II \cup III \cup IV$  is equidecomposable with a

(3) rectangle R of dimensions  $a + c$  and  $2b$ .

To prove this we assume  $T = ABC$  to be made of stiff paper, and we dissect it into the four polygons (1). These we assume to be hinged at the three points F, E, and D.

We now perform three turning operations as follows:

1°. We turn IV about the hinge F by  $+180^\circ$ , obtaining IV' of Figure 2.

2°. We turn the union  $III \cup IV'$  about the hinge E by  $+180^\circ$ , obtaining

III' IV'' of Figure 3.

3°. We turn the union  $II \cup III' \cup IV''$  about the hinge D by  $+180^\circ$ , obtaining the final union  $I \cup II' \cup III'' \cup IV'''$  of Figure 4.

If we observe the various segments of length

$1, \xi, 1 - \xi, a, b$ , and  $c$ ,

as indicated in Figure 1, and also in Figures 2, 3, and 4, we find the final figure of Figure 4 to be a rectangle R of dimensions as described by (3). This proves our claim.

So far the position of the point  $P = (\xi, 0)$ , of Figure 1, has remained arbitrary. Now we wish to determine  $\xi$  so that the rectangle R should become a square. By (3) this will be the case, provided that

(4)  $a + c = 2b$ .

We evidently need the length a, b, and c, as functions of  $\xi$ . From Figure 1 we find that

$$(a + c)^2 = (DF)^2 = (\xi + \frac{1}{2})^2 + \frac{1}{4}3 = \xi^2 + \xi + 1,$$

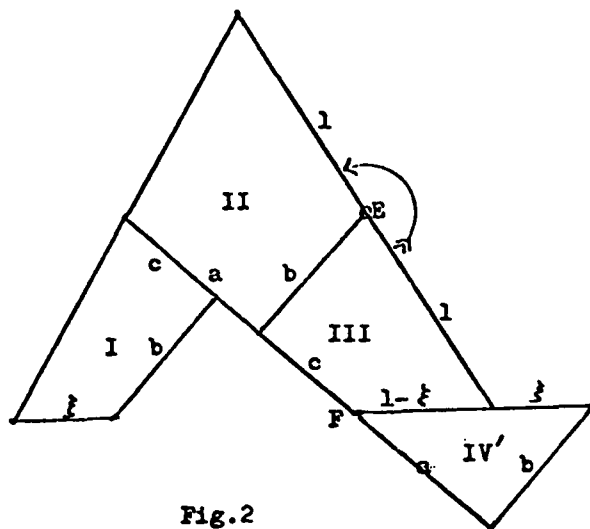


Fig. 2

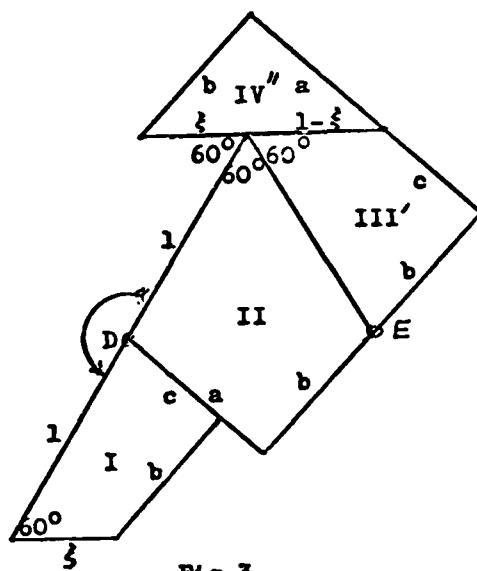


Fig. 3



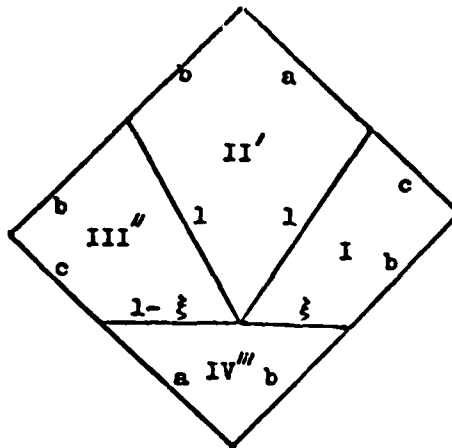


Fig.4

whence

$$(5) \quad a + c = \sqrt{\xi^2 + \xi + 1}.$$

Observe next that the normal form of the equation of the line DF is found to be

$$DF: \quad \frac{\sqrt{3} x + (1 + 2\xi)y - \sqrt{3} \xi}{2\sqrt{\xi^2 + \xi + 1}}$$

This gives the distance b from E to the line DF to be

$$b = \frac{1}{2} \sqrt{3/(\xi^2 + \xi + 1)},$$

whence

$$(6) \quad 2b = \sqrt{3/(\xi^2 + \xi + 1)}.$$

The desired equation (4) becomes

$$(7) \quad \xi^2 + \xi + 1 - \sqrt{3} = 0,$$

its solution being

$$(8) \quad \xi = \frac{-1 + \sqrt{1 + 4(\sqrt{3} - 1)}}{2} = .490985.$$

This accuracy should be sufficient for the realization of the ingenious linkage of four polygons (1) as described by Steinhaus (See [2, Figure 1.3 on page 2]).

Returning to the incorrect solution as given in [3, Figure 2 on p. 4], we observe that it assumes that the parallelogram DEFG of our Figure 1 is a rectangle. This gives the value  $\xi = .5$ , which represents a relative error of 1.8%.

That the "solution"  $\xi = 1/2$  can not possibly be correct is immediately apparent from our Figure 1: Indeed, it would imply that DEFG is a non-square rectangle and therefore

$$a + c = DF = EG > GH + JE = b + b = 2b,$$

and the equation (4) does not hold.

#### REFERENCES

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2. I. J. Schoenberg, Mathematical time exposures, Math. Assoc. of America, 1982.
3. Hugo Steinhaus, Mathematical snapshots, 3<sup>rd</sup> American Edition, Oxford University Press, Oxford, 1983.

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